FastMRI: High-Quality Brain MRI Reconstruction

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Introduction

Compressed Sensing (CS) MRI accelerates imaging by reconstructing high-quality images from undersampled k-space data, crucial for reducing scan times in clinical settings. Generative Adversarial Networks (GANs) provide effective solutions for rapid CS-MRI reconstruction. Our project initially developed DR-CAM-GAN, a U-net-based model with Dilated Residual (DR) networks and Channel Attention Mechanisms (CAM), to reconstruct brain MRIs from the NYU fastMRI dataset at 4× and 8× acceleration. Due to training instability, we transitioned to Wasserstein GAN with Gradient Penalty (WGAN-GP), achieving improved performance with PSNR increasing from 29.1793 dB to 31.1499 dB and SSIM from 0.7834 to 0.8302, enhancing diagnostic potential for brain imaging.

Methodology

Dataset: NYU fastMRI brain MRI dataset

Training Process

- DR-CAM-GAN: Trained with standard GAN loss (binary cross-entropy), optimizing a U-net generator with DR networks and CAM for feature enhancement.
- WGAN-GP: Transitioned to Wasserstein loss with gradient penalty to stabilize training at 10× CS acceleration.

Evaluation Metrics

- Peak Signal-to-Noise Ratio (PSNR): Measures pixel-level accuracy.
- Structural Similarity Index (SSIM): Assesses perceptual quality.

Implementation: PyTorch, Adam optimizer, trained on NVIDIA RTX 3090 GPU.

Challenges and Advantages

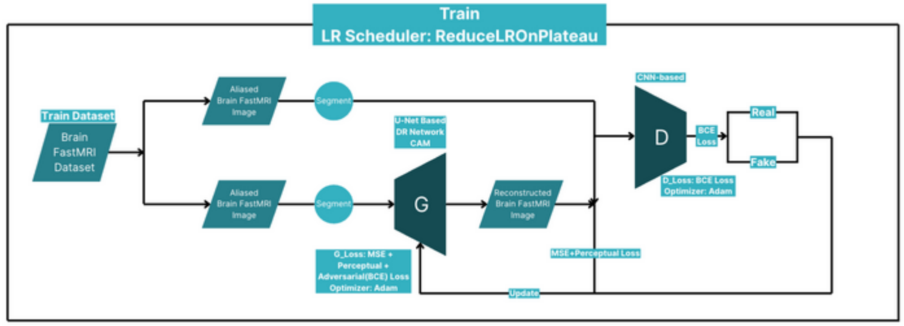
DR-CAM-GAN Challenges:

- Mode collapse due to Jensen-Shannon divergence, leading to limited sample diversity.
- Unstable convergence at 8x acceleration, impacting reconstruction quality for complex brain MRIs.

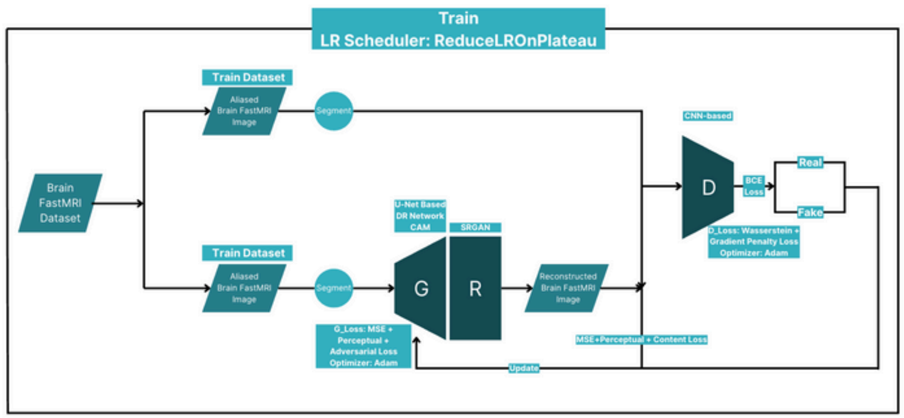
WGAN-GP Advantages:

- Wasserstein loss provides smoother gradients, reducing vanishing gradient issues.
- Gradient penalty replaces weight clipping, improving convergence and stability.

Architecture (DR-CAM-GAN)



Architecture (WGAN-GP)



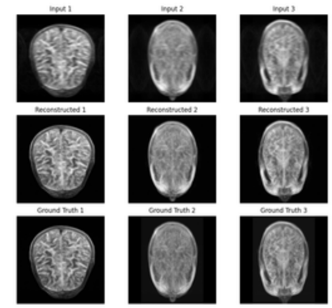
Refinement Layer

Purpose: Enhance reconstructed MRI quality by focusing on anatomical details.
Implementation: CAM with global max/avg pooling to weigh channel importance, reducing background noise and emphasizing key features.
Ablation Study: CAM reduced background artifacts, improving diagnostic relevance.

Future Work

1. Adopt StyleGAN2 or Progressive GAN for ultra-high-resolution brain MRI reconstruction.
2. Apply model to fastMRI knee/prostate datasets for multi-organ applicability.
3. Reduce computational cost via mixed-precision training or optimized architectures.
4. Develop 3D CS-MRI reconstruction for volumetric brain imaging, aiding surgical planning.

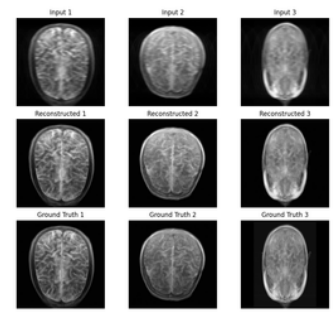
Test Result for DR-CAM-GAN



PSNR 29.1793

SSIM 0.7834

Test Result for WGAN-GP



PSNR 31.1499

SSIM 0.8302

Conclusion

The U-net with DR and CAM, paired with WGAN-GP's stable Wasserstein loss and gradient penalty, improved PSNR from 29.1793 dB to 31.1499 dB and SSIM from 0.7834 to 0.8302. These gains highlight WGAN-GP's potential and SRGAN's refinement skill to deliver high-quality, reliable brain MRI reconstructions, paving the way for advanced clinical applications.

References

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